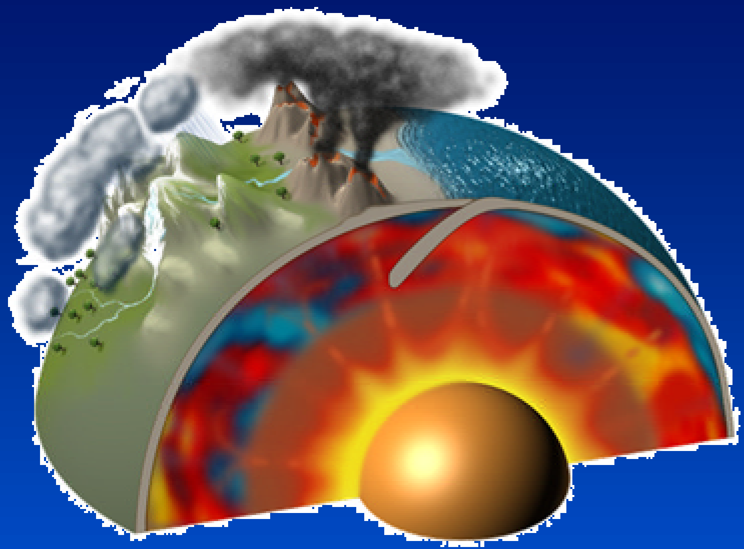
Predicting Solid Earth Interactions with Climate and the Effects on Habitability of Earth



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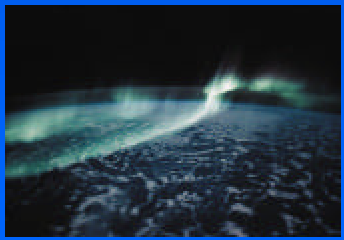
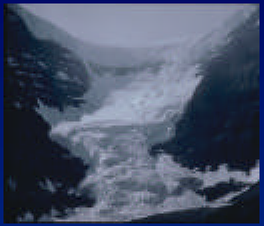
Topics

- Global Sea Level
  - Interaction between ocean volume and coastal evolution

- Volcanic Emissions
  - Interaction between atmospheric loading and climate variations

- Magnetic Field
  - Interaction between energetic particles and atmospheric dynamics?



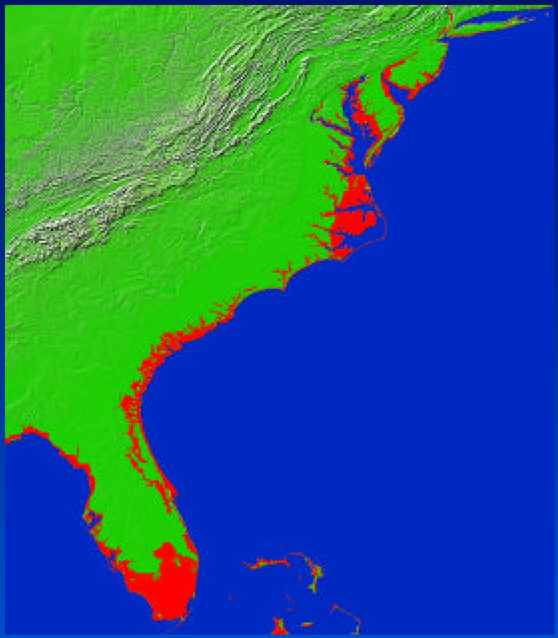


Sea Level Change results from interactions and feedbacks between changes in the volume and mass of the oceans and the shape of the ocean basins

- Highly **interdisciplinary:** climate, oceanography, glaciology, hydrology, geophysics
- Phenomena which **integrates multiple sources**; similar to climate change modeling
- Requires many different **measurement** types; some continuing, some new
- Requires new climate-change and geophysical **models**
- Data quality requirement: high. Quantity: moderate

Motivation

- More than 100 million persons now live within one meter of mean sea level and the number will grow
- Sea level rise is accelerating as climate changes - projected rise is 10's of centimeters over the 21st century
  - Current rate is 1-2 mm/yr
- Regional changes could be significantly different than the global average
- Sea level rise exacerbates coastal vulnerability to storm surge due to extreme weather which is expected to increase in frequency as climate warms



The potential rise in sea level caused by melting of the Greenland ice sheet seriously jeopardizes low-lying areas such as the Florida coast. Red shows where land would be submerged for an estimated ***5-m sea-level rise.***

Challenges for Sea Level Prediction

- Knowledge of ice sheet dynamics and present mass balance of Antarctica and Greenland
- Knowledge of thermal expansion pattern of ocean water as climate warms
- Coupling of climate and ice sheets
- Quantification of regional viscoelastic response to ice mass changes
- Regional changes likely more important than global average

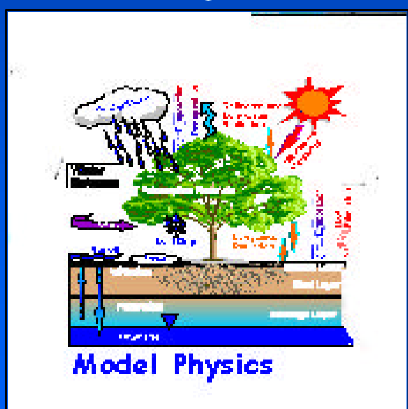
Sea Level Prediction Goals to 2030

Today	2015	2030
Large uncertainties in several significant potential contributors to sea level rise (ice sheets, coastal change)	Ice sheet state, evolution and dynamics understood	Accurate 10-yr and longer regional sea level prediction, including impacts on coastal erosion, coastal ecosystems and fresh water availability
Rudimentary knowledge of short-term ocean volume changes	Well-understood oceanic expansion term tied to short-term climate prediction models	
Regional variability poorly understood	Variable coastal response to sea level change understood	
Rudimentary knowledge of adaptability of coastal ecosystems to rising sea level	Impact of sea level change on coastal region habitability coming into focus	

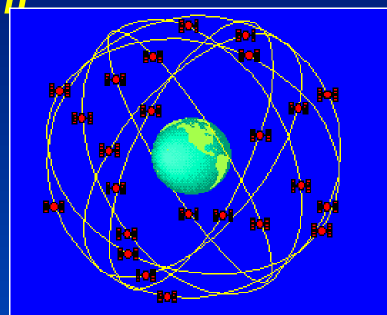
Predicting the Earth’s future: *Sea level change*

NEED:

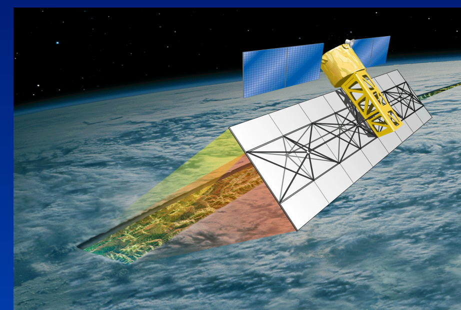
- ***Surface Hydrology (Soil Moisture, stream flow, reservoir storage etc.)***
- ***Ocean thermohaline circulation***
- ***Air-Sea interactions***
- ***Atmospheric water vapor***



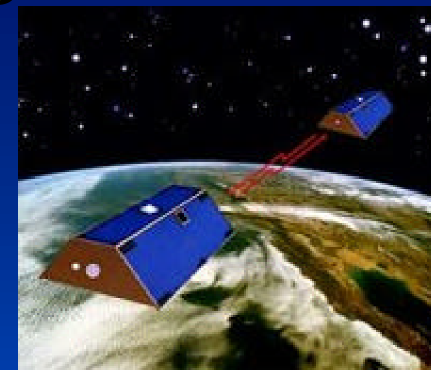
PLUS:



Geodetic Reference Frame



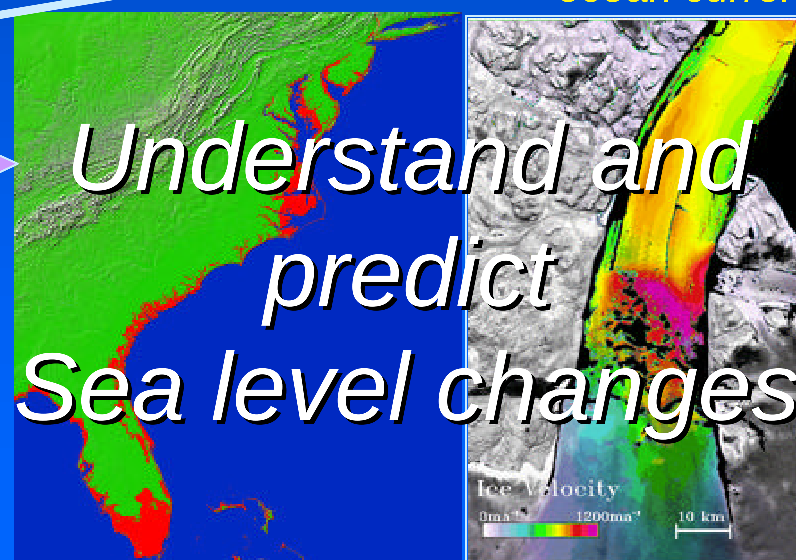
InSAR/LIDAR for glacial rebound, volume, coastal subsidence



Time-variable gravity for Ice mass change, glacial rebound, water redistribution and deep ocean currents

Data assimilation and Modeling for:

- Global hydrological/cryological mass fluxes
- Separation of steric (thermal and salinity) and mass-budget contributions
- Solid Earth vertical motion



Understand and predict Sea level changes

Sea Level Measurement Needs

Sea Level Measurements	Frequency	Horizontal Resolution	Precision/ accuracy
Ocean/Ice Mass Redistributions (gravity change)	Monthly	100s-1000s km (scale of drainage basin)	0.1 mm/yr sea level rise equivalent
Bathymetry	Once	5 km	10%
Ocean mixed layer depth	Weekly	10 km	10%
Coastal zone topography	Monthly	2-5 m pixels	<10 cm (height)
Ice Sheet Topographic Change	< 1 Year	1-10 km (ice streams – ice sheet)	1 cm (height)
Ice motion (dynamics)	Monthly	100 m	1 m/yr (rate)
Ice Sheet and Bed Characteristics	10 Years	10 – 100 km	Bed topography to <10 m
Crustal Deformation (uplift/subsidence)	Daily To Weekly	10 m	1 cm (range) 0.5 mm/yr (rate) on annual basis
Soil Moisture	Daily	< 1 km	10%
Snow Pack	Weekly	< 1 km	0.1 mm/yr sea level rise equivalent
Reservoir and Aquifer Impoundment	Monthly	Scale of storage basin	0.1 mm/yr sea level rise equivalent

Observational Requirements

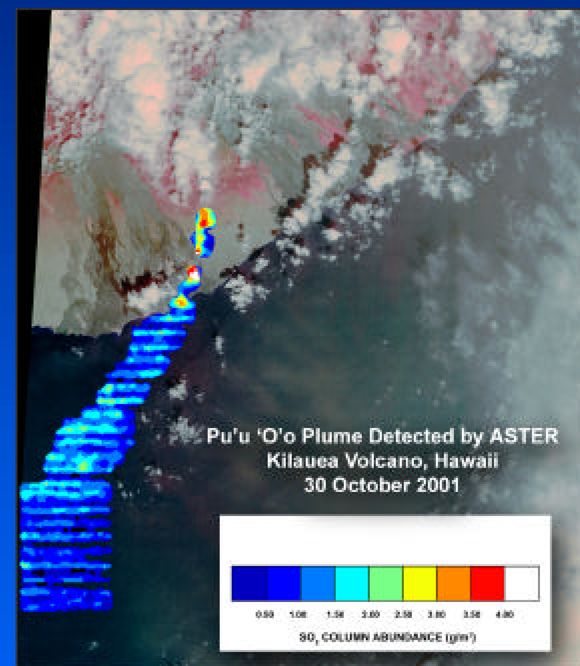
- Need all the observations required for accurate medium-term climate prediction
- Need continuing time-variable gravity measurements with greater accuracy
  - Laser metrology for satellite-satellite tracking and drag-free orbits
- Need dedicated InSAR data for ice sheet dynamics and coastal uplift/subsidence (mantle viscosity)
  - Single polar LEO orbiter is sufficient if data are taken continuously over ice sheets
- Need high-resolution, wide-swath laser altimetry for ice sheet height changes
- Need stable absolute reference frame to sub mm-level accuracy (GPS/Glonass/Galileo, VLBI, SLR)

Modeling Requirements

- Ice Sheet mass change and solid Earth response
- Ocean volume change resulting from climate change
- Vulnerability of coastal regions to erosion and storm surge

Volcano/Climate Interactions

- Volcanoes emit gases to the atmosphere both during active eruptions and in quiet phases
  - SO_2 example shown
- Volcanoes present a non-linear input to climate models
- Large eruptions increase particulate load that may affect decadal climate

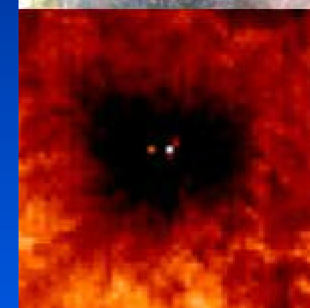


Passive SO_2 plume from Kilauea detected by ASTER

Motivation

- Historically, volcanoes have had huge impacts on climate
  - Final push into Dark Ages may have been due to volcanic activity
- Global inventory of active volcanoes is poorly known
  - Recent ASTER and ERS data indicate activity at several volcanoes in the Andes and Cascades previously thought to be inactive
- Budget of passive emissions (SO_2, CO_2) is poorly known and could be important for climate models

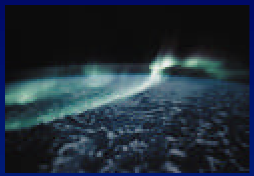
Chiliques, Chile



Three Sisters

Observational Strategies

- High temporal resolution thermal infrared imaging
  - Geostationary orbit for continuous monitoring
  - UAV for event monitoring
- InSAR and gravity for monitoring volcano dynamics and eruption forecasting
  - High vantage point (geosynchronous or MEO) for high temporal resolution
- Multispectral imaging to measure SO_2 flux
  - Need high temporal resolution to measure highly dynamic flux (geostationary orbit)
  - UAV for event monitoring

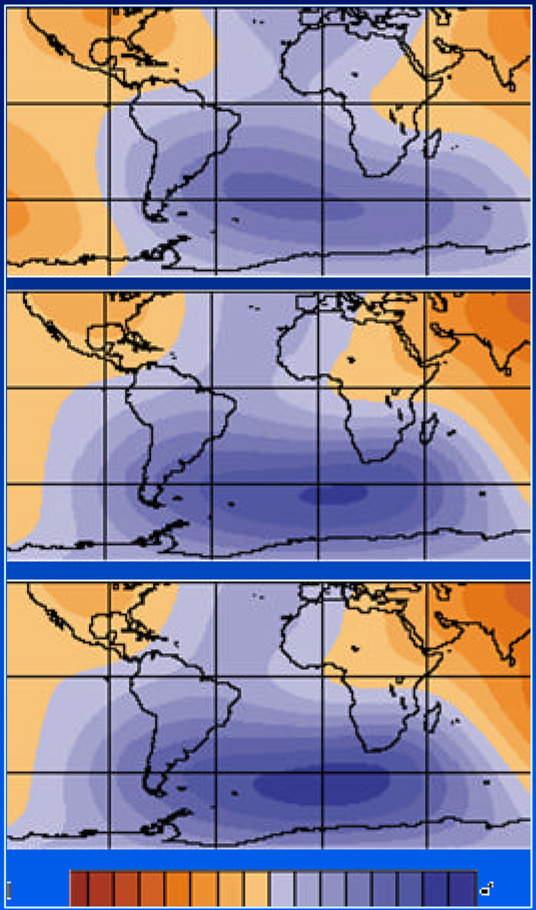


Magnetic Field/Climate Interactions

- Influence of space weather (solar energetic particle activity) on atmospheric temperature and dynamics has been suggested
  - Effects are part of natural variability
  - Quantification is important due to 11-year solar cycle and decadal climate oscillations
- Magnetic field strength is decaying and secular variation (time-varying higher order terms) causes significant variations
  - Shielding of the atmosphere from cosmic rays and high energy solar particles may decrease
  - Patterns of energy deposition may be altered

Motivation

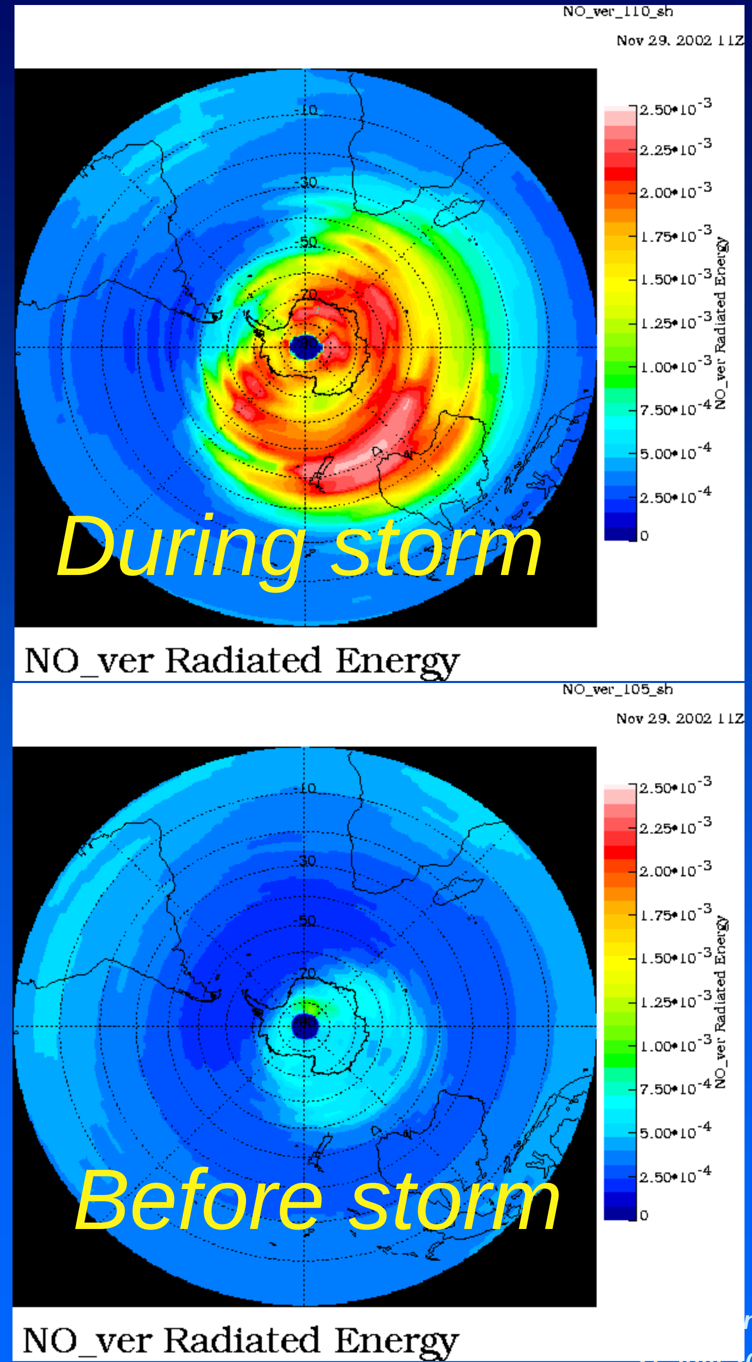
- 11-year solar cycle and the Earth's magnetic field mediate cosmic ray and high-energy electron bombardment in the upper atmosphere
  - This results in Joule heating and may alter cloud microphysical properties
- Observed decay in magnetic dipole field strength and particularly the South Atlantic Anomaly may increase the influence of energetic particles on the atmosphere
- Interactions and causes and effects of observed phenomena are poorly understood

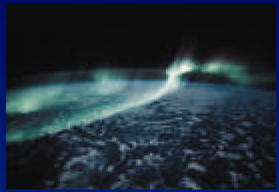


South Atlantic Magnetic Anomaly strength at 500 km altitude over the last 100 years. It's about 35% weaker than would be expected.

Recent TIMED Results

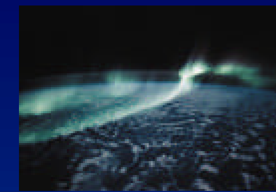
- Thermosphere-Ionosphere Mesosphere Energetics and Dynamics satellite with Sounding of the Atmosphere using Broadband Emmsion Radiomenter (SABER) instrument-10 bands 1.27-15 um, scans surface to ~ 350 km.
- A major magnetic storm in April 2002 caused a dramatic increase in energy radiated by NO at 5.3 microns resulting in thermospheric cooling
- TIMED is providing a first look at the energy balance of the MLTI region





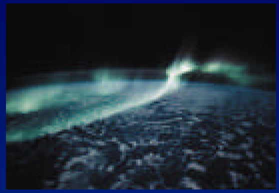
Measurement Needs

- High-resolution, continuous spatial and temporal coverage of magnetic field fluctuations to model field dynamics and energy deposition
  - *swarm (ESA)* and follow-on
- High spatial and temporal resolution measurements of high-energy particle flux
- High spatial and temporal resolution measurements of mesosphere lower thermosphere / ionosphere (MLTI) energy balance



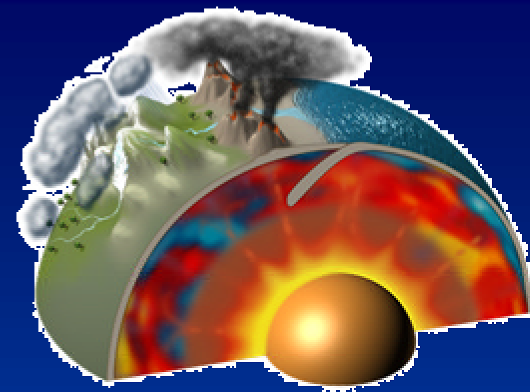
Observational Strategies

- Magnetic field constellation using high LEO (1000 km) and very low LEO (300 km) polar and inclined orbits
- Continue TIMED measurements with increased resolution
  - Need multiple satellites in order to definitively resolve the tides



Research Goals

- Characterize and understand the causes of observed correlations of atmospheric temperature and solar cycle
- Model the core geodynamo processes to understand the generation and variation of the geomagnetic field
- Understand and predict magnetic field evolution (i.e. SAA) to understand future influence on the atmosphere
- Couple magnetic field dynamics and particle flux and energy distribution into short-term climate models



Summary and Conclusions

- Coupling of next-generation climate models and new understanding of ice sheet dynamics and solid Earth motion will enable useful sea level change prediction if new observations and models are realized
- Inventory of active volcanoes and understanding of the medium and long-term effects of eruptions on atmospheric chemistry and dynamics is needed to develop useful uncertainties on climate models
- Solar influence on the atmosphere and mediation by the dynamic magnetic field is a high priority focus for solid earth/climate coupling